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Indian Standard

ELECTROMAGNETIC INTERFERENCE CHARACTERISTICS OF OVERHEAD POWER LINES AND HIGH VOLTAGE EQUIPMENT

PART 1 DESCRIPTION OF PHENOMENA

Section 1 Radio Noise from Power Lines

UDC 621·391·893 [621·396] : 621·315·1

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BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

Gr 5

June 1988

Indian Standard

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Section 1 Radio Noise from Power Lines

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Indian Standard

ELECTROMAGNETIC INTERFERENCE CHARACTERISTICS OF OVERHEAD POWER LINES AND HIGH VOLTAGE EQUIPMENT

PART 1 DESCRIPTION OF PHENOMENA

Section 1 Radio Noise from Power Lines

0. FOREWORD

0.1 This Indian Standard (Part 1/Sec 1) was adopted by the Bureau of Indian Standards on 31 July 1987, after the draft finalized by the Electromagnetic Compatibility Sectional Committee, had been approved by the Electronics and Telecommunication Division Council.

0.2 The purpose of Part 1 series of standards is to discuss the physical phenomena involved in the generation of electromagnetic noise fields. This also includes the main properties of such fields and their numerical values.

0.3 The technical data given in these standards will be useful aid to overhead line designers and also to any one concerned with checking of electromagnetic noise performance of a line to ensure satisfactory protection of wanted electromagnetic signals.

0.3.1 The technical data should facilitate the use of recommendations which will be given in Parts 2 and 3 of this standard. Various parts are proposed to be issued as given below:

Part 1 Description of phenomena
Part 2 Methods of measurement and procedure of determining limits
Part 3 Code of practice for minimizing the generation of radio noise.

0.4 The standard is proposed to be issued in the following sections, which would clarify only one aspect over the electromagnetic interference due to overhead power lines and high voltage equipment:

Section 1 Radio noise from power lines
Section 2 Effects of corona from conductors
Section 3 Radio noise levels due to insulators, fittings and sub-station equipment (excluding bad contacts)

Section 4 Sparking due to bad contacts

Section 5 Special DC effects

0.5 This standard has been largely based on CISPR Publication 18-1 (First Edition-1982) 'Radio interference characteristics of overhead power lines and high voltage equipment, Part 1 Description of phenomena, issued by the International Special Committee on Radio Interference of the International Electrotechnical Commission (IEC).

0.6 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test shall be rounded off in accordance with IS : 2-1960*. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

1. SCOPE

1.1 This standard (Part 1/Sec 1) deals with radio noise from overhead power lines which may cause interference to radio/TV reception.

1.2 The frequency range covered is 0·15 MHz to 300 MHz.

2. TERMINOLOGY

2.1 For the purpose of this standard, the definitions given in IS : 1885 (Part 36)-1972† shall apply.

3. GENERAL

3.1 Radio noise from high voltage, that is to say above 1 kV, overhead power lines may be generated over a wide band of frequencies by:

a) corona discharges in the air at the surfaces of conductors and fittings,

b) discharges and sparking at highly stressed areas of insulators, and

c) sparking at loose or imperfect contacts.

The sources of (a) and (b) are usually distributed along the length of the line but source (c) is usually local. For lines operating above about 100 kV, the electric stress in the air at the surface of conductors and fittings can cause corona discharges. Sparking at bad contacts or broken or cracked insulators can give rise to local sources of radio noise. High voltage apparatus in sub-stations may also generate radio noise which can be propagated along the overhead lines.

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*Rules for rounding off numerical values (*revised*).

†Electrotechnical vocabulary: Part 36 Radio interference.

3.2 If the field strength of the radio noise at the aerials used for receiving broadcast sound and television services is too high, it can cause degradation of sound output and, in the case of television, the picture may also be affected.

3.3 The generation of radio noise is affected by weather conditions, for example, conductor corona is more likely to occur in wet weather because of the water droplets which form on the conductors whereas, under these conditions, bad contacts can become bridged with water and the generation of radio noise, by this process, ceases. Consequently, loose or imperfect contacts are more likely to spark in dry weather conditions. Dry, clean insulators may cause interference in fine weather, but prolonged sparking on the surfaces of insulators is more likely to occur when they are polluted, particularly during wet, foggy or icy conditions.

3.4 For the interference-free reception of radio and television signals, it is important that a sufficiently high ratio is available at the input to the receiver between the level of the wanted signal and the level of the unwanted radio noise. Interference may, therefore, be experienced when the signal strength is low and the weather conditions are conductive to the generation of radio noise.

3.5 When investigating radio noise, it should be borne in mind that the local field may be caused by a distant source or sources as the noise may be propagated along the line over a considerable distance.

4. PHYSICAL ASPECTS OF RADIO NOISE FROM POWER LINES

4.1 Mechanism of Formation of a Noise Field — Corona discharges on conductors, insulators or line fittings or sparking at bad contacts can be the source of radio noise as they inject current pulses into the line conductors. These propagate along the conductors in both directions from the injection point. The various components of frequency spectrum of these pulses have different effects.

In the frequency range from 0·15 MHz to a few megahertz, the noise is largely the result of the effect of propagation along the line. Direct electromagnetic radiation from the pulse sources themselves does not materially contribute to the noise level. In this case, the wavelength is long in comparison with the clearances of the conductors and thus the line is not an efficient radiator. However, associated with each spectral voltage and current component, an electric and a magnetic field propagates along the line. In view of the relatively low attenuation of this propagation, the noise field is determined by the aggregation of effects of all the discharges spread over many kilometres along the line on either side of the reception point. It should be noted that close to the line, the guided field predominates whereas further from the line, the radiated field predominates. The change-over is not abrupt and the phenomena is not well known. This effect is not important at low frequencies but is apparent at medium frequencies.

However, for spectral components above 30 MHz where the wavelengths are close to or less than the clearance of the line conductors, the noise effects can be largely explained by aerial radiation theory applied to the source of noise, as there is no material propagation along the line. It should be appreciated however, that 30 MHz does not represent a clear dividing line between the two different mechanisms producing noise fields.

4.1.1 *Longitudinal Propagation* — In the case of a single conductor line mounted above the ground there is simultaneous propagation of a voltage wave $U(t)$ and a current wave $I(t)$.

For a given frequency the two quantities are related by the expression $U(\omega)=ZI(\omega)$ where Z, also a function of ω, is the surge impedance of the line.

During propagation, the waves are attenuated by a common coefficient 'a' where:

$$U_x=U_o\,e^{-ax}$$
$$I_x=I_o\,e^{-ax}$$

U_o and I_o are the amplitudes at the source and X is the distance of propagation along the line.

In the case of multi-phase lines, experience shows that any system of voltages or currents becomes distorted in propagation, that is to say, the attenuation varies with the distance propagated and it differs for each conductor. Theory of propagation and actual measurements on power lines have shown that noise voltages on the phase conductors can be considered as being made up of a number of 'modes', each one having components on every conductor. One mode propagates between all conductors in parallel and earth. The others propagate between conductors. Each mode has its own different propagation attenuation. It is important to note that the attenuation of the conductor-to-earth mode propagation is fairly high, that is to say 2 dB/km to 4 dB/km, while the attenuation of the various conductor-to-conductor modes is a small fraction of 1 dB/km at a frequency of 0·5 MHz.

4.1.2 *Electromagnetic Field* — The voltages and currents propagating along the line produce an associated propagating electromagnetic field near the line. It should be noted here that in free space, the electric and magnetic fields associated with radiated electromagnetic waves are at right angles both to each other and to the direction of propagation.

The ratio of their amplitudes represents a constant value:

$$\frac{E\,(\mathrm{V/m})}{H\,(\mathrm{A/m})} = 377\Omega$$

and is called the intrinsic impedance or impedance of free space.

On the other hand, the fields near the line are related to radio frequency voltages and currents propagating along the line and their ratio depends on surge impedance of the line for the various modes. Furthermore, the directions of the electric and magnetic fields differ from those for radiated fields in free space as they are largely determined by the geometrical arrangement of the line conductors. The matter is further complicated by the fact that soil conditions affect differently the mirror image in the ground of the electric and magnetic field respectively. The electric field $E\,(y)$ at ground level of a single conductor line, which is the vertical component of the total electric field, is given by the approximate formula based on simplified assumptions:

$$E\,(y) = 120\,I \frac{h}{h^2 + y^2}$$

where I is the current, in amperes, propagating in the conductor, h is the height, in metres, of the conductor and y is the lateral distance, also in metres, from a point directly under the conductor to the measuring point.

Furthermore, for an infinitely long single conductor line, the induction zone, or near fields, has the same simple ratio of electric and magnetic field as the far field from a radio transmitter, that is to say 377 Ω and this is approximately true for all values of ground conductivity.

In the case of a multi phase line, the electric field is the vectorial sum of the individual fields associated with each phase conductor A more comprehensive treatment, together with practical methods of assessing the electromagnetic field, will be discussed in 'Indian Standard Electromagnetic Interference Characteristics of Overhead Power Lines and High Voltage Equipment: Part 2 Methods of Measurement and Procedure for Determining Limits (*under consideration*). The formula given above is a simplified version accurate for $D = 20$ m and $f = 0{\cdot}5$ MHz where D is the distance, in metres, between the measuring set aerial and the nearest conductor of the line and f is the measurement frequency. For a wider range of D and f it would be necessary to take into account all the parameters affecting the formula.

4.1.3 *Aggregation Effect*— In the case of uniformly distributed noise sources, the field generated by a unit length of a phase conductor can be expressed at any point along the line as a function of the longitudinal distance x and the lateral distance y, that is to say, $E(\,y,\,x\,)$. At a given lateral distance of y.

$$E(\,y,\,x\,) = E_o\,(\,y\,)\,e^{-ax}$$

The random pulses on a long line with uniformly distributed noise sources combine together to form the total field. The manner in which they combine is not unanimously agreed upon. Some investigators consider that they combine quadratically:

$$E^2(y) = 2\int_0^\infty E^2_o(y)\, e^{-2ax}\, dx, \text{ or}$$

$$E(y) = \frac{E_o}{\sqrt{a}}$$

Other investigators believe that, if a quasi-peak detector is used to measure the field strength, the individual pulses do not add and others have obtained results between the two extremes. This disagreement is only important in analytical prediction methods, the results obtained by different methods vary by only 1 or 2 dB.

In the case of multi-phase lines, the calculation follows the same principle but is complicated by the presence of several modes, each mode having a different attenuation coefficient. A more detailed discussion with examples of calculation, is given in Section 2 of this standard.

4.2 Definition of Noise — The instantaneous value of noise varies continuously and in a random manner, but its average power level over a sufficiently long period, for example, 1 s, gives a stationary random quantity which can be measured. Another quantity suitable for measurement is the peak or some weighted peak value of the noise level. A noise measuring set is basically a tuneable, selective and sensitive voltmeter with a specified pass-band. When connected to a suitable rod or loop aerial and properly calibrated, it can measure the electric or magnetic component of the noise field.

Depending on design of the measuring apparatus, the noise level can be measured in terms of rms peak or quasi-peak values. The rms value defines the noise in terms of energy. Many types of noise from electrical equipment, as well as noise due to power-line corona, consist of a succession of short pulses with approximately stable repetition frequencies. In such cases, the nuisance effect of noise can be realistically indicated by a quasi-peak type of voltmeter rather than by rms type. The quasi-peak value is obtained from a circuit which includes a diode and a capacitor with relatively short charge and long discharge time constants. The voltage on the capacitor floats at a value somewhat below the peak value and depends on the repetition rate, that is to say a weighting feature is included in the response. The noise level is thus defined by the value measured by such an instrument, expressed in microvolts or microvolts per metre. Using the ratio of the electric to magnetic fields, $E/H = 377$, the measured values can be expressed by convention in microvolts per metre even for instruments using a loop aerial responding to the magnetic field.

4.3 Influence of External Parameters — To determine the corona inception gradient g_c of a cylindrical conductor with smooth surface, Peak's formula is often used:

$$g_c\text{ (kV/cm)}=31\ \delta\left(1+\frac{0{\cdot}308}{\sqrt{\delta r}}\right)$$

For ac voltages, g_c is the peak value of the gradient, r is the radius of the conductor in centimetres, $\delta=\dfrac{0{\cdot}294\ p}{273+t}$ is the relative air density ($\delta=1$ for p = 1 013 m bar and t = 25°C).

However, practical conditions on overhead lines do not agree with these idealized assumptions. Stranding of the conductors, surface imperfections and irregularities lead to local enhancements of the electric field and consequently to a lower corona inception voltage, that is, obtained from the above formula. This often means that the critical gradient for initiating radio noise is, under foul weather conditions, about half the value given by Peak's formula. Atmospheric conditions likewise play an important part. In conditions of rain, fog, snow or dew, drops of water are formed on the surface of the conductor and at low temperatures ice can also form.

With regard to bad contacts and the production of small sparks, the effect of rain and humidity is to bridge the relevant gaps either by water droplets or by humid layers, thus reducing the level of this type of noise. Rain and humidity thus affect corona noise from conductors in a way opposite to that due to bad contacts. Hence, when interference is observed during rain or fog, it can be concluded that it is caused by corona. On the other hand, when interference is observed during fine weather and disappears during rain or fog, it is due to bad contacts.

5. MAIN CHARACTERISTICS OF NOISE FIELD RESULTING FROM CONDUCTOR CORONA

5.1 General — To rationalize the measurement of radio noise from a transmission line and facilitate comparison between different lines, it is desirable to standardize the conditions under which the measurement is to be carried out.

The main characteristics of the noise field are the frequency spectrum, the lateral profile and the statistical variation of noise with weather conditions. It is assumed as a first approximation that these characteristics are independent of each other.

5.2 Spectrum — The spectrum is the variation of radio noise measured at a given point in the vicinity of a line, as a function of the measurement frequency. Two phenomena are involved:

a) *Current Pulses* — The current pulses generated in the conductors by the discharges show a particular spectrum dependent on the pulse shape. For this type of discharge, the measured noise level falls with frequency. In the range of broadcasting frequencies, where the positive discharges have predominant effect, the spectrum is independent of the conductor diameter.

b) *Attenuation* — The attenuation of noise propagating along the line increases with frequency. This effect modifies the spectrum by reducing still further the noise level with increase in frequency.

The measured spectra are often fairly irregular because of the standing waves caused by discontinuities such as angle or terminal towers or abrupt ground level variations. In addition, the noise generation might vary whilst the measurements are being made.

For all prediction calculations, standard spectra are used. Experience has shown that all spectra can be put into two families, one applying to horizontal conductor configurations, the other to double-circuit and triangular or vertical conductor configurations. The difference between these two families originates from the phenomenon mentioned in item (b) above, the propagation differing slightly according to the type of line. However, as the difference is not material in relation to the accuracy of such calculations, only one standard spectrum is given in relative values, the reference point being taken at 0·5 MHz.

The following formula is a good representation of this spectrum:

$$\triangle E\,(\text{dB}) = 5\,[1 - 2\,(\log 10f)^2]$$

where

$\triangle E$ (dB) is variation of radio noise level from the reference frequency of 0·5 MHz and f is the frequency expressed in megahertz over the range 0·15 to 4 MHz.

It should be noted that other investigators have developed different formulas which give similar results.

At higher frequencies, the noise spectra are more difficult to produce.

5.3 Profile — The variation of noise fields as a function of distance from the line is characterized by a decrease depending on the frequency. Measurements are taken along a perpendicular to a midspan which is as close as possible to an average span of the line under consideration. The proximity of sub-stations or interconnections, sharp angles, neighbouring lines and great variations in level of terrain must be avoided.

The profile is determined at a height of 2 m above the ground from a point immediately beneath an outside conductor over a distance not exceeding 200 m. Beyond this distance, the noise level of the lines generally becomes negligible. The reference frequency is 0·5 MHz.

The measured profiles are often irregular both because of the continual fluctuations of the radio noise during a series of measurements and because of irregularities such as angle or terminal towers and terrain variations.

Numerous measurements carried out under some fifty different lines have provided a good experimental knowledge of these profiles, which has been confirmed by theoretical calculations.

An accurate analysis has enabled profile to be plotted as function of classes of line voltage and configuration up to distances of about 100 m, beyond which the noise level is normally so low that reliable measurements are not practicable.

In the vicinity of a power line there are two noise fields, the direct or guided field and the radiation field. The latter is a result of irregularities in the line such as conductor sag and changes in line direction and imperfect ground conductivity. The direct field decreases as the square of the distance, the radiation field decreases directly as the distance. Close to the line the direct field predominates, whereas at greater distances the radiation field predominates. Based on certain aerial concepts, the two fields may be expected to be equal at a distance of around $300/2\pi f$ metres where f is in megahertz. In fact, the lateral attenuation close to the line falls off less rapidly than the square of the distance, for example, *see* Fig. 1 and 2. The attenuation factor k for frequencies between 0·5 and 1·6 MHz, for example, is 1·65. Close to the line, the lateral attenuation may be described by:

$$E = E_o + 20\,k \log D_o/D$$

where

E = noise level, in decibels (1 μ V/m) at distance D,

k = attenuation factor, and

E_o = noise level, in decibels (1 μ V/m) at the reference distance D_o.

Further from the line, the attenuation factor gradually decreases until it reaches a value of unity. Some investigators consider that the two fields are equal at around $300/2\pi f$ metres as discussed above. The equation shows the profile in the 0·4 to 1·6 MHz band, assuming that the distance is 100 m from the line.

Standard profiles are shown with a logarithmic scale of distance referring to a direct distance to the conductor of 20 m. This presentation shows the physical law of the noise field decreasing as a function of the distance from the nearest conductor. The profiles can also be presented as a function of the lateral distance. This presentation is useful for predicting the width of the corridor subject to interference.

5.4 Statistical Distribution — The systematic study of fluctuations in the radio noise level of a line necessitates the continuous recording of the field strength under this line for at least a year at a fixed distance from the line and with a fixed measurement frequency. Numerous researchers, in many countries, have carried out such measurements with the result that there is in existence fairly reliable data on the annual or seasonal variations in radio noise level. These results are often presented according to statistical analysis methods, that is to say in the form of histograms or as cumulative distributions. The latter express the percentage of time during which the radio noise level was less than a given value.

The most important causes of fluctuations in recorded radio noise level are :

a) the random nature of the phenomenon;

b) variation of meteorological conditions, both at the measuring point and along the few tens of kilometres of the line which contribute to the local interference; and

c) changes in the surface state of the conductors, which is affected not only by weather conditions such as rain and frost, but also by deposits of dust, insects and other particles.

These causes are very difficult to measure systematically. Even variations of the applied line voltage result in fluctuations in the radio noise level but this cause is possible to measure.

The distribution of the noise levels likewise depends on the type of climate; a very humid climate, a rainy one, or one with abundant snow or frost will increase the percentage of high levels whereas a very dry climate will reduce it.

The curves in Fig. 3 to 6 in a temperate climate show examples of an all weather distribution survey, together with a dry weather distribution and an average heavy rain distribution. It can be seen that the overall curve is more or less a combination of two or three Gaussian distributions.

On such an all-weather distribution, it is customary to define several characteristic levels:

a) The 99 percent level is practically the highest possible level of the line, at a given point;

b) The average heavy-rain level is the most stable and reproducible and the rainfall is considered to be heavy when it reaches 0·6 mm or more per hour. For this reason, the average heavy-rain level is often chosen as the reference level for the calculation of radio noise. Practically, the average heavy-rain level is a 95 percent level and is about 5 dB lower than the 99 percent level;

c) The average fair weather level, corresponding to dry conductor conditions. This is important for practical purposes, but, due to the larger dispersion, a greater number of measurements throughout the year is necessary to obtain reliable results. Fortunately, measurements are more easily made in average fair weather than in average heavy rain;

d) The 50 percent level, read on all-weather cumulative curve. This 50 percent level must not be confused with the above defined average fair weather level, since it arises not only from dry weather conditions but also from the whole range of climatic conditions prevailing during the long term recordings. Both the average fair weather and 50 percent levels are furthermore strongly dependent on the surface state of the conductors; these levels can vary over a range of more than 10 dB according to whether or not the conductors are polluted, greasy, etc. Some experts consider that the 50 percent level will not vary by more than 10 dB over a relatively long period, say, a month or a year, even though individual readings may vary by more than 10 dB; and

e) The 80 percent level, read on all-weather distribution curve, is chosen as the characteristic value, to be used as the basis for limits. This 80 percent level, intermediate between the fair weather level and the average heavy-rain level, is probably less subject to uncertainties than the 50 percent level and for this reason, is preferred as the characteristic level. A survey of numerous cumulative curves shows that the difference between 95 percent and 80 percent levels lies between 5 and 12 dB. As mentioned in **5.3**, it should be remembered that beyond about 100 to 200 m, reliable measurements are not normally practicable.

The above generalized guidelines are illustrated in Fig. 3 to 6, related to 400 to 750 kV lines, and are valid for lines where the predominant noise source is conductor corona.

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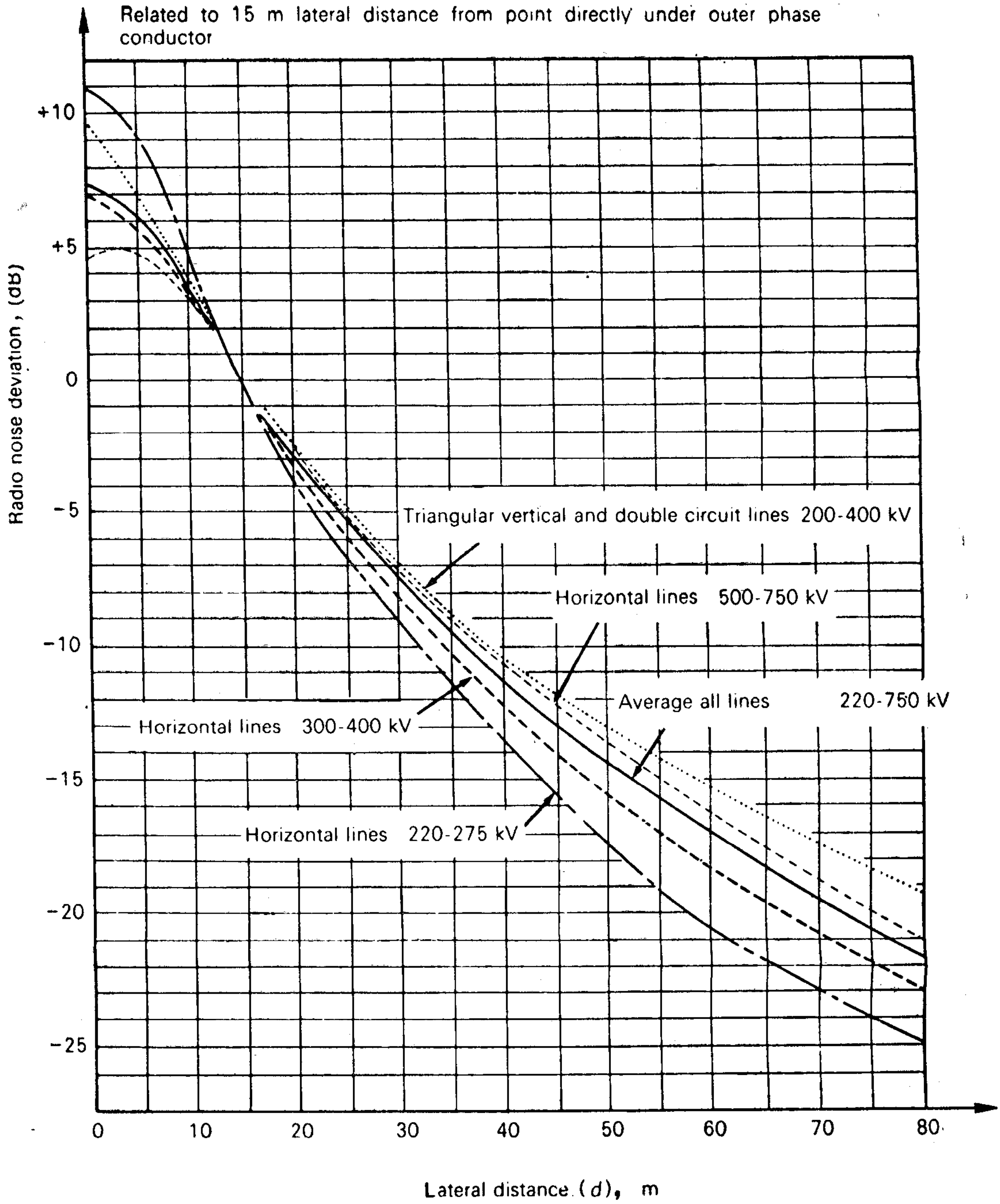


FIG. 1 TYPICAL LATERAL ATTENUATION CURVES FOR HIGH VOLTAGE LINES

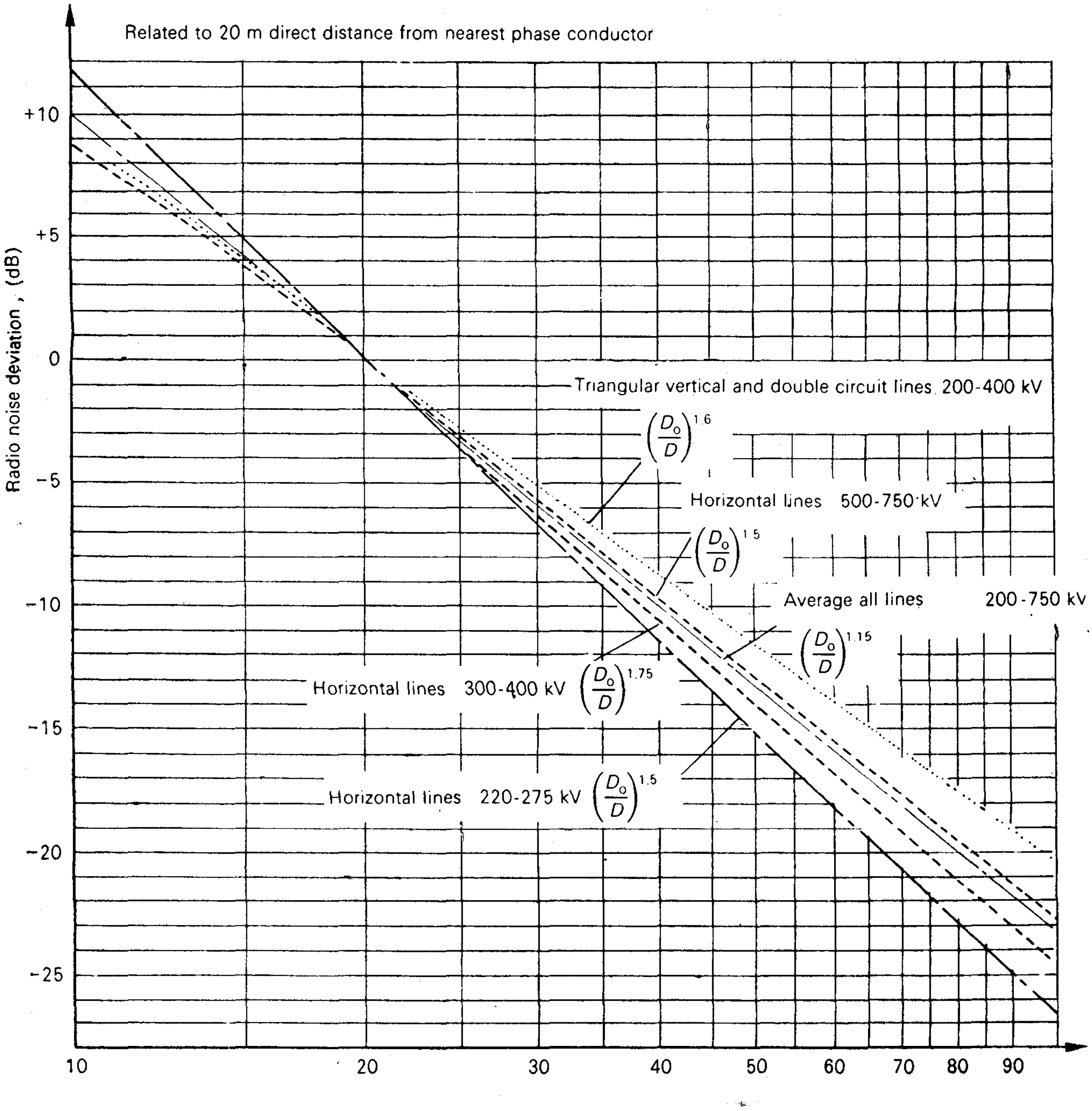
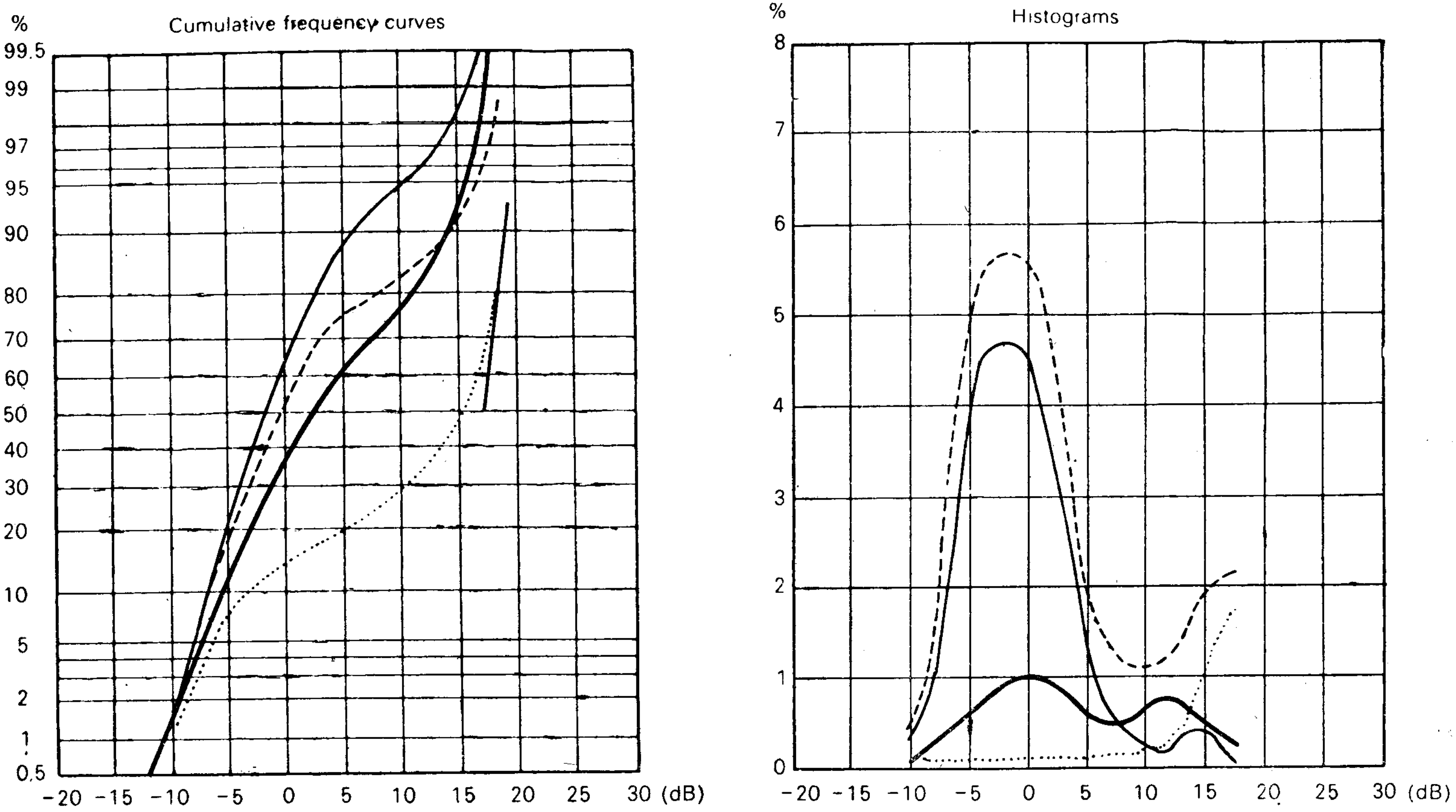


FIG. 2 TYPICAL LATERAL ATTENUATION CURVES FOR HIGH VOLTAGE LINES



3A

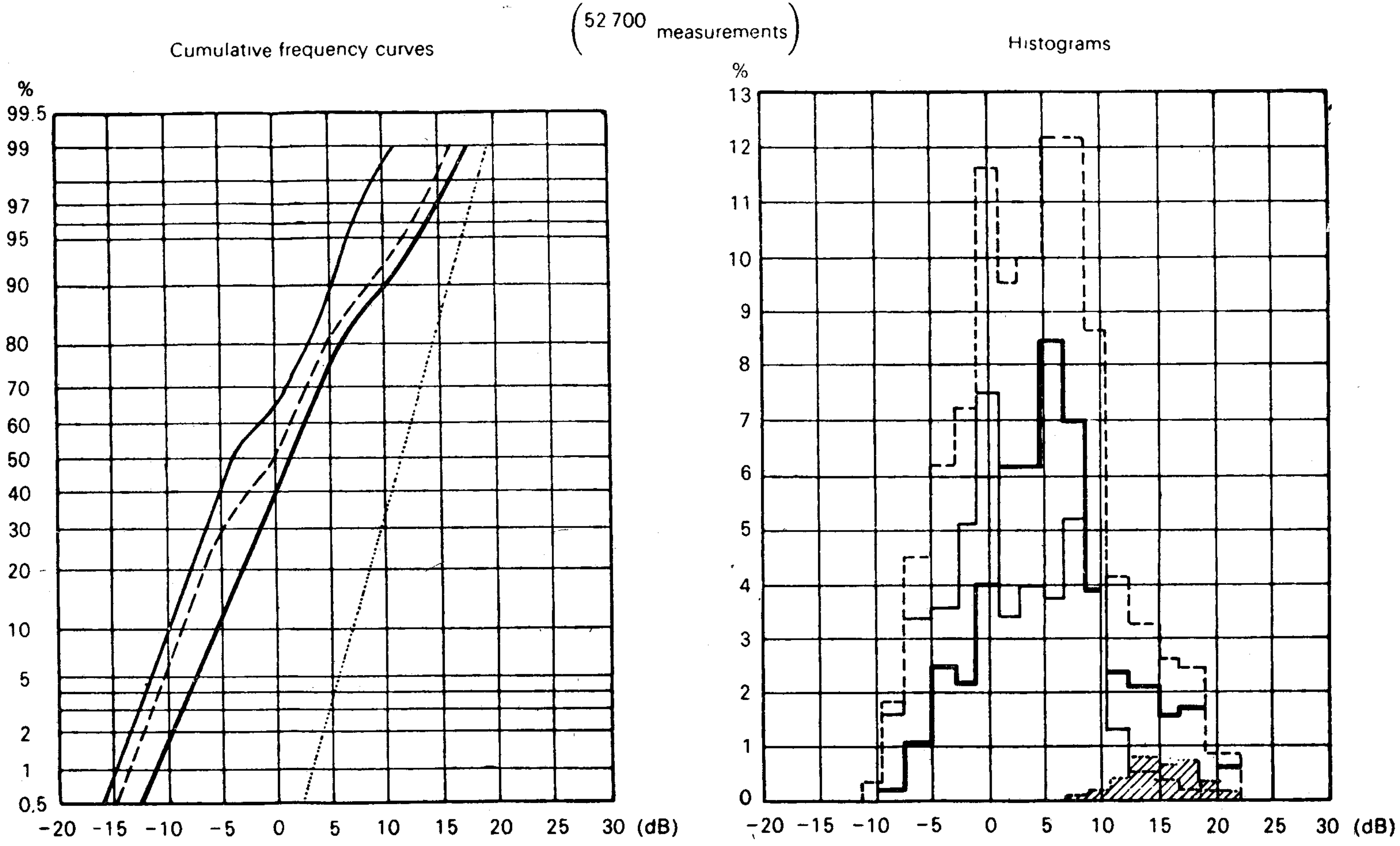
3B

. . . . 100 percent Overall — 66 percent fair weather — 21 percent immediately before and after rain ...... 13 percent rain

Relative radio-noise levels: dB (μV/m) 50 percent, all weathers

420 kV line — Single 50 mm conductor — Voltage gradient 15 kV/cm

FIG 3. EXAMPLES OF STATISTICAL YEARLY DISTRIBUTIONS OF RADIO-NOISE LEVELS RECORDED CONTINUOUSLY UNDER VARIOUS OVERHEAD LINES

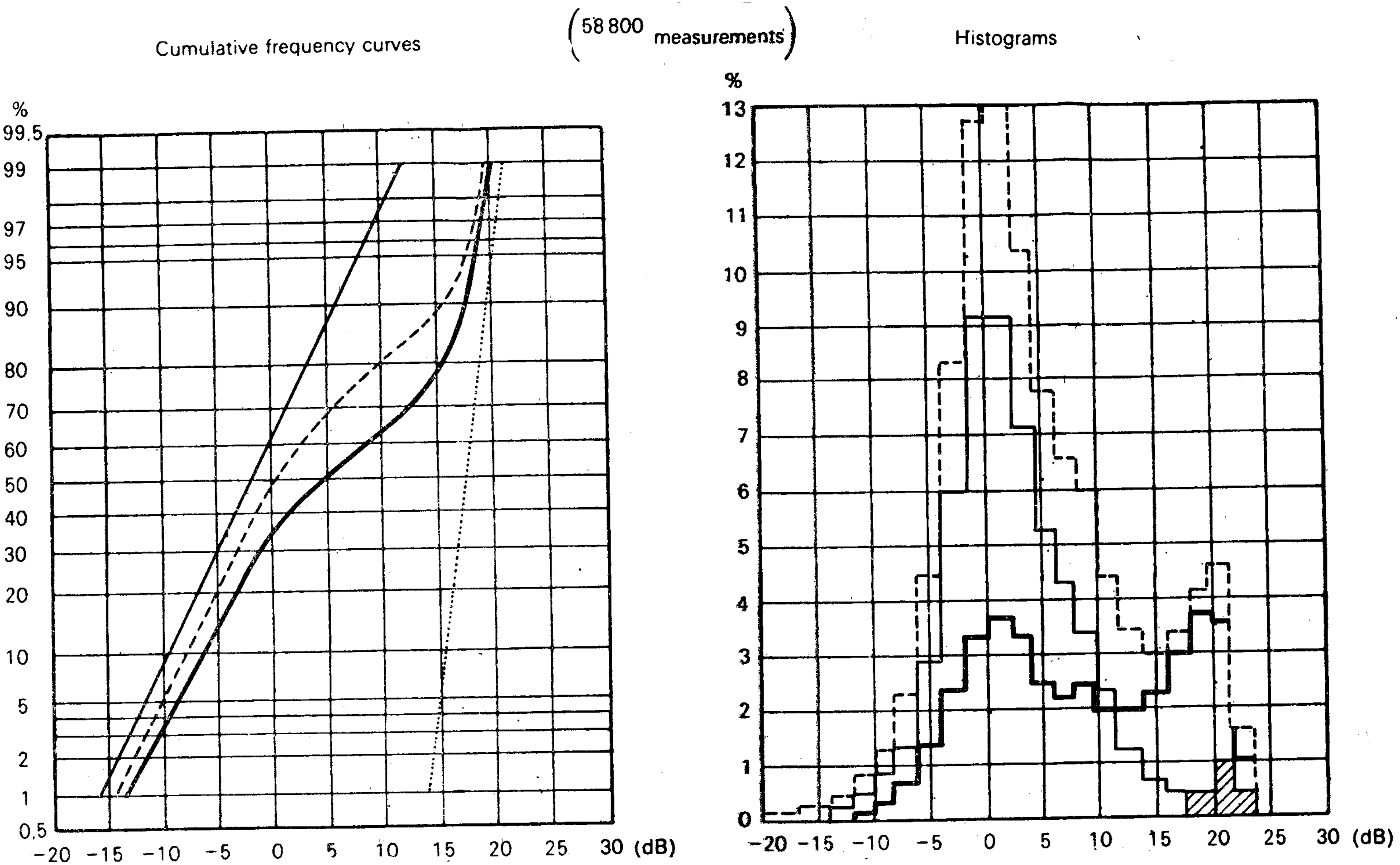


4A

4B

...100 percent overall — 45 percent fair weather — 52 percent foul weather+light rain ... 3 percent heavy rain (⩾ 0·6 mm/h)
Relative radio-noise levels: dB (μ V/m) 50 percent all weathers
400 kV line — 2 × 26·4 mm conductors

FIG. 4 EXAMPLES OF STATISTICAL YEARLY DISTRIBUTIONS OF RADIO-NOISE LEVELS RECORDED CONTINUOUSLY UNDER VARIOUS OVERHEAD LINES



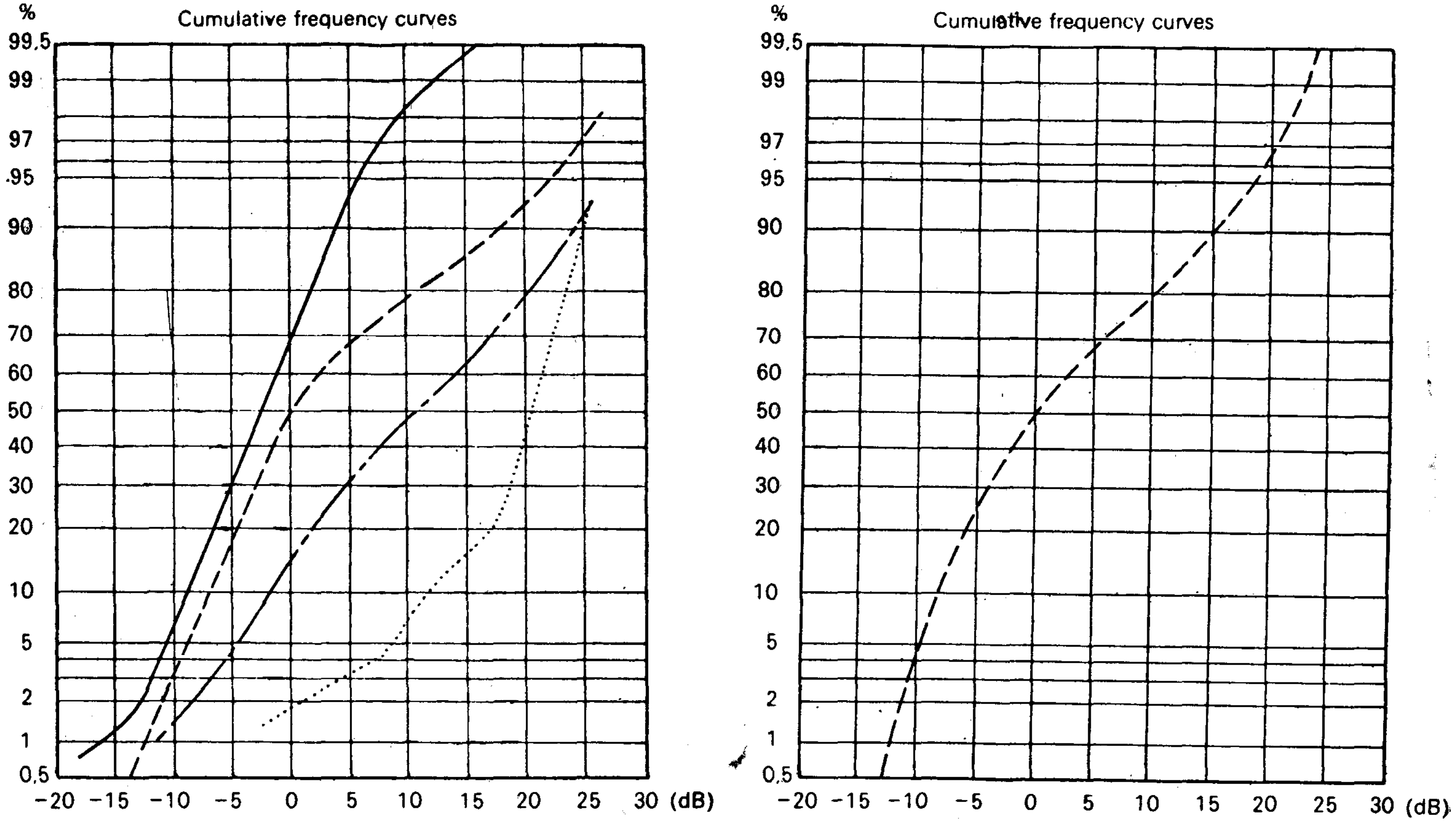
5A 5B

... 100 percent overall — 56 percent fair weather —42 percent **foul weather** + light rain ... 2 percent heavy rain (⩾ 0·6 mm/h)

Relative radio-noise: dB (μ **V/m) 50** percent, all weathers

Experimental line (1·2 **km long) at** 750 kV

FIG. 5 EXAMPLES OF STATISTICAL YEARLY DISTRIBUTIONS OF RADIO-NOISE LEVELS RECORDED CONTINUOUSLY UNDER VARIOUS OVERHEAD LINES



6A

100621 readings — 7·3 percent fair weather
... 100 percent overall — 2·5 percent hoar-frost
... 0·2 percent rain

6B

2 542 Readings
...... overall

Relative radio-noise levels: dB (μV/m) 50 percent, all weathers — Conductor 2×593 mm^2, ACSR Line 525 kV 400 kV line

FIG. 6 EXAMPLES OF STATISTICAL YEARLY DISTRIBUTIONS OF RADIO-NOISE LEVELS RECORDED CONTINUOUSLY UNDER VARIOUS OVERHEAD LINES

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Printed at Swatantra Bharat Press, Delhi (India)